Climate Change

Photograph courtesy of Bruce G. Marcot

Modeling Approaches for Predicting Change Under WILDCAST: Making Progress in a Data-Poor World

By Bruce G. Marcot

Abstract

A basic framework is suggested for knitting together models of climate change, vegetation, and wildlife habitats and species, for use in the U.S. Geological Survey, Alaska Science Center's WILDCAST Program. The framework also addresses influence of climate change on key ecological functions of organisms and on ecosystem services of value to people. Many of the linkages among models will require expert interpretation. Tools and approaches to formalizing that expertise are suggested, as are next steps in the modeling process.

Background: The WILDCAST Vision

The U.S. Geological Survey (USGS), Alaska Science Center has initiated a major new program to produce a documented, knowledge-based forecasting tool called the WILDlife Potential Habitat ForeCASTing Framework (WILDCAST). WILDCAST is intended to help predict potential influences on species, communities, wildlife habitats, and ecosystems from climate change over the next century.

WILDCAST is a major undertaking. To be successful, it must span and knit science and models of global and regional climate including effects of climate change on subsurface and exposed water and ice; vegetation response and dynamics; interpretation of vegetation and environmental conditions in terms of habitat and resources for wildlife; interpretation of wildlife species and population responses to changes in habitats and environmental conditions; and how all these changes influence the functions of, and services provided by, ecosystems.

Figure 1. Drained lake in Bering Land Bridge National Preserve.

The tools and models developed under WILDCAST should also provide insight into the types, degrees, and implications of uncertainty in each of these linkages, as well as the expected sensitivity of outcomes to various scenarios of climate change and environmental conditions.

A Framework for WILDCAST

The basic linkages can be depicted as an influence diagram (*Figure 2*). Note the explicit presence of unknown and unmodeled effects, and also, in the bottom right of the diagram, the feedback arrow that represents how ecological functions of organisms can affect the occurrence and distribution of other organisms.

Modeling Questions

There are many possible objectives and purposes for the WILDCAST tool, including: 1) to describe some pattern, 2) to compare a pattern with some goal, 3) to explain the pattern (mechanisms), 4) to predict outcomes in other geographic areas, 5) to predict outcomes in future time periods, 6) to diagnose problems, 7) to identify best parameters for monitoring, 8) to identify best parameters for conservation, and other possible uses. No one modeling system can fully achieve all of these objectives, so it will be critical to clearly define what WILDCAST will be expected to do.

Similarly, it will be helpful to identify the intended audience(s) for the WILDCAST tool. They might include researchers and scientists, managers in land management agencies, politicians, the general public, local communities, the courts, attorneys, and others. Some of these audiences, such as scientists, embrace uncertainty, whereas others want to dispel doubt and desire answers in simple terms. To satisfy all audiences will be a challenge.

The stated purpose of WILDCAST is to forecast climate change and its influence on vegetation, land cover, and wildlife response. But how accurate do forecasts need to be? Accuracy pertains to

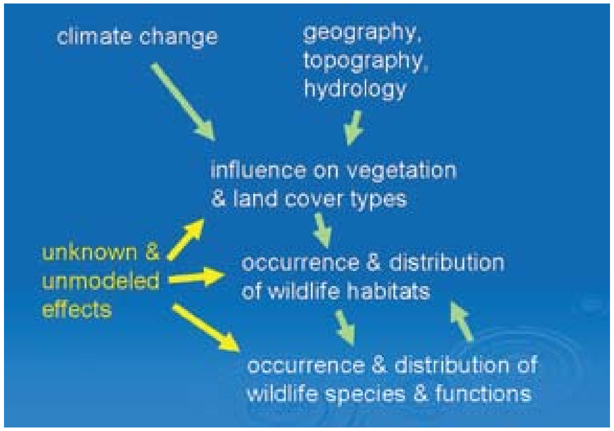

Figure 2. An overall "influence diagram" framework of model linkages for use in U.S. Geological Survey's WILDCAST Program of evaluating climate change.

Photograph courtesy of Bruce G. Marcot

Figure 3. An example of a "key ecological function" of wildlife. A black bear has dug out this log in search of grubs to eat. The log and woody material now can be readily invaded by fungi, bacteria, and insects that will break down the wood into organic matter and nutrients to be taken into the soil, and the cavity can be occupied by rodents, and other species. In this way, the action of the bear provides ecological services and functions benefitting other species and the ecosystem. How will such functions be affected by the influence of climate change on the bear's habitats and food sources?

correctly forecasting the trajectory of change. Would forecasting just the direction of change be enough? How should uncertainty play a role in forecasting accuracy?

Many forecasting models produce predictions that increase in uncertainty over future time periods; that is, the rangeof possible future conditions spread out over time. The spread represents increasing uncertainty, which can be represented in the models as increasing variance, a widening confidence interval, and other measures of variation. A familiar example is the spread of the potential tracks of hurricanes, where the most likely track is depicted with the most severe forecast of a hurricane warning, and less likely tracks shown, in decreasing severity, as areas of hurricane watch, tropical storm warning, and tropical storm watch. In a similar way, forecasting climate change and its effect on wildlife habitats, species, functions, and ecosystem services may be depicted with increasing uncertainty over time, with various possible outcomes shown with probabilities and various levels of warnings. Combining outcomes with probabilities is the basis for risk analysis, where warnings of "risk" refer to probabilities of not achieving some stated goal or desired outcome.

In addition, how precise do forecasts need to be? Precision pertains to how fine the increments of change can be forecasted and depicted. What are acceptable levels of spatial or temporal resolution in the forecasts? That is, what are acceptable levels of habitat and species occurrence, abundance, and distribution?

Answering questions of objective, purpose, audience, accuracy, and precision – as well as related questions of bias, consistency, and area of application – will help guide development of the WILDCAST tool but will not necessarily eliminate uncertainty and the need to use expert judgment.

Working With Uncertainty

Climate, being inherently variable and often chaotic, is the paragon of uncertainty (*Mitchell 2007*). But uncertainty is information that can be of value to decision-makers who deal with questions of risk management and managing systems that are chaotic or poorly understood.

Thus, WILDCAST is an example of complex ecological interactions and outcomes with no simple analytical solution. There are a number of rules of thumb, or tips and tricks, to solving analytically intractable problems. For example, one approach is to decompose the problem into more tractable and solvable sub-problems, to split the model, so to speak. Then, it can become easier to build, test, and update the submodels. Examples of submodels are functions of individual species-habitat relationships (e.g., resource selection for particular species).

Another approach to tackling difficult problems is to make the best estimates for variables and their relationships, based on expert judgment. Expert panels can be used to provide a range of possible values and functions. Competing models can be evaluated for their specific forecasting ability, and the best one(s) chosen for application.

A third approach is to use a combination of information sources, such as expert panels, statistical methods of combining information and meta-analysis, and use of traditional local knowledge.

Beginning the WILDCAST Modeling Work

A simple but useful approach to framing the models for WILDCAST is to build influence diagrams, also known as concept maps, cognitive maps, mental maps, and mind maps. Figure 2 is an example of an influence diagram. Influence diagrams depict the major components of a system and how they relate functionally or logically. A number of computer software programs are available for creating influence diagrams, including Microsoft's PowerPoint, Mindjet's MindManager, Inspiration, Personal Brain, Norsys' Netica, cMap, and FreeMind (the latter two being freeware).

One step up from an influence diagram is to statistically denote the strength of the connections in the diagram. Strengths can be shown in various ways, including partial correlations as used in path regression models, strengths of evidence as used in fuzzy logic models, and transition probabilities as used in Markov chain models. Note that the uncertainty portion in Figure 2 can be included to show the relative influence of uncertainty in the model. Various approaches to estimating strength of connections are available, including structural equation modeling, which is a generalized approach to statistically formalizing relationships among variables such as with regression and factor analysis.

If the connections in an influence diagram are depicted with functions, the system can then be depicted as a process simulation model. One commercially-available modeling shell is the STELLA program which produces time-based projections of values of variables.

The Wildlife Connection

Wildlife-habitat relationships (WHR) models pertain to the bottom two segments of our WILDCAST influence diagram (*Figure 2*) – predicting species from habitats. WHR models typically take the form of a matrix or data table in which species are listed down the rows and various habitat or land cover types are listed across the columns, and cells are filled in according to the presence or strength of relation between the two. WHR models are often created from a variety of information sources including expert judgment and experience, anecdotal observations, field studies, and literature reviews. Examples of WHR models include databases built for terrestrial wildlife species in Oregon and Washington (*Johnson and O'Neil 2001*) and in the interior Columbia River Basin of the inland west U.S. (*Marcot et al. 1997*).

WHR models can extend well beyond simple depictions of habitat types. The Johnson and O'Neil WHR model has been extended as a relational database to include information on wildlife habitats, habitat structures (structural or successional stages of vegetation), key environmental correlates, and influence of management activity on habitats and environmental correlates, as well as categories of key ecological functions and life history attributes of each species. Further extensions can include categories of key cultural values of each species, which depict how local communities and cultures value and use organisms for a variety of needs and purposes. Developing such extensive WHR models for the WILDCAST project should be possible and would provide great value for evaluating climate change effects not just on wildlife but also on human communities.

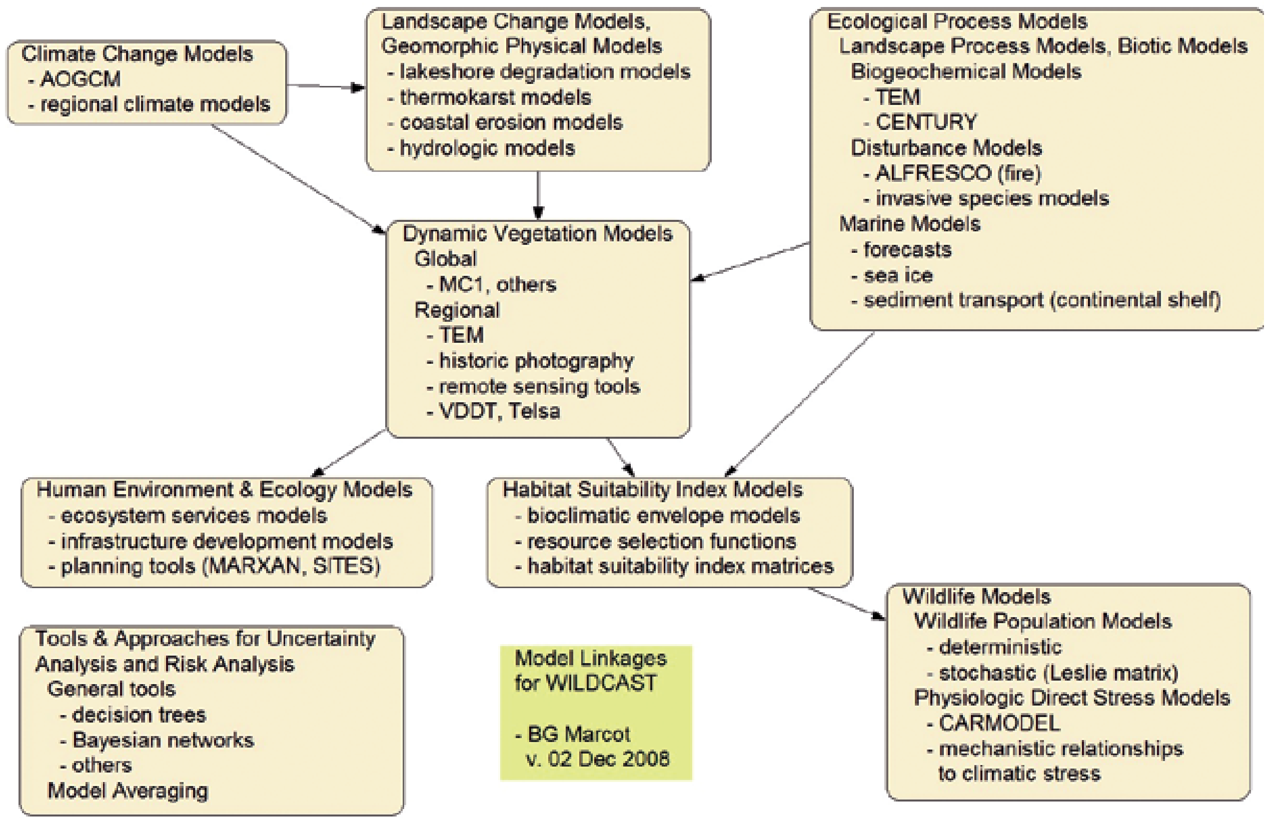

Figure 4. A fuller expression of the WILDCAST influence diagram shown in *Figure 2*, denoted with specific models and topics.

Key Ecological Functions and Ecosystem Services

The WILDCAST tool could explicitly include the influence of key ecological functions (KEFs) of organisms: the way that ecological roles of wildlife can alter environmental attributes and habitat suitability for other species. Examples of KEFs include primary cavity-excavating birds (e.g., woodpeckers) creating tree hollows occupied by a host of secondary-cavity using species (e.g., some small owls, squirrels); species of insects and some birds (orioles, hummingbirds) that pollinate flowering plants; and organisms (pileated woodpecker, black bear) that strip or tear apart dead trees, thus providing coarse organic matter for incorporation into soils (*Figure 3*). I have developed an extensive, hierarchical classification system of KEFs and used it in various WHR models to evaluate the functional patterns of a variety of wildlife assemblages and communities (*e.g., Marcot and Aubry 2003*), including how conditions of habitat and environment provide one set of species whose KEFs influence habitats and environments for other species.

WILDCAST also could be designed to forecast influence of climate change on ecosystem services. Ecosystem services are those resources and ecological processes that are of value to people and that can serve to sustain a natural ecosystem. Examples include water filtration by wetlands, pollination of crop plants by native bees, carbon sequestration by trees, medicinal uses of native plants, and many other categories. A growing field of environmental economics is beginning to valuate ecosystem services (*e.g., Brown et al. 2006*), and such estimates could be included in the WILDCAST framework.

Where To Next?

The next steps in the WILDCAST program might involve answering questions raised here about scope, purpose, and audience, and then questions of model accuracy, precision, and related attributes.

In October 2008, a workshop was held in Fairbanks to begin the process of identifying the various components and submodels of the WILDCAST influence diagram presented here, and how they might begin to be linked (*Figure 4*). Making linkages among the submodels will likely require expert judgment and interpretation (*Ayyub 2001*). One possible method for identifying linkages is use of formal expert panels or other knowledge engineering approaches to develop probabilistic structures such as Bayesian networks (*Van Allen et al. 2008*). Bayesian networks could depict the degree to which the output of one model, such as a vegetation condition model, would serve as a proxy input variable for another model, such as a wildlife habitat model. I have successfully used this approach in developing Bayesian network models of wildlife-habitat relationships.

With the advent of the National Climate Change and Wildlife Science Center in Lansdowne, Virginia, recently formed by the USGS, modeling effects of climate change will certainly continue to garner great interest and concern from a host of audiences, partners, and stakeholders in natural resources management.

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Photograph courtesy of Bruce G. Marcot

Figure 5. View of the Schwatka Mountains in Gates of the Arctic National Park and Preserve.

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